# DMT PEAK REDUCTION WITHOUT AFFECTING TRANSMISSION SIGNAL

## BACKGROUND OF THE INVENTION

1. Field of the Invention

**[0001]** This invention relates to the field of data communication, and in particular to a method of reducing signal peaks in a Discrete Multitone (DMT) signal.

2. Description of Related Art

**[0002]** DMT or Discrete Multitone is a multicarrier transmission technique that uses a Fast Fourier Transform (FFT) and inverse FFT to allocate transmitted bits among many narrow narrowband QAM modulated tones depending on the transport capacity of each tone. This of course can vary with transmission conditions. As is known in the art, QAM (Quadrature Amplitude Modulation) is a passband modulation technique wherein information is represented as changes in carrier phase and amplitude.

**[0003]** DSL or Digital Subscriber Line is a system wherein a non-loaded local loop provides a copper connection between a network service provider and customer premises. DMT is a common form of modulation used in DSL systems. In a DMT based DSL system, the required peak-to average ration (PAR) of a signal is 15 dB for the probability of a clipping occurring to be $10^{-8}$ (assuming a Gaussian distribution).

**[0004]** A large PAR value will seriously reduce the signal dynamic range. On the one hand, any peak value will cause signal saturation and the error will spread at all frequency subcarriers. In the worst case, the entire frame of a signal can be wiped out. On the other hand, if the PAR is increased so that the signal has less chance of being clipped, the dynamic range is lost. For the case where PAR=15 dB, the signal will normally be transmitted 15 dB below its peak level.

**[0005]** In a DMT system, multiple QAM constellations are modulated on different carrier frequencies. In the time domain, the signal has variable levels. Normally, the maximum peak-to-average ratio ranges from 27 dB to 39 dB depending on the size of FFT. To increase the signal dynamic range and reduce the PAR, several methods have been used in DMT based DSL systems. The most efficient method is to use a special waveform known as a signature waveform. This is a time domain signal which has a large peak in it and is

otherwise small at other time instants. Whenever the signal is larger than a maximum level, the signature waveform is subtracted from the signal so that the signal will not be saturated. However, addition of the signature waveform will generally cause distortion to the transmission signal.

[0006] Prior art peak reduction systems are described, for example,, in J.Tellado and J.Cioffi, "PAR Reduction in Multicarrier Transmission System", ANSI Contribution T1E1.4/97-367, Sacramento, CA, December 1997; and A.Gatherer and M.Polley, "Controlling Clipping Probability in DMT Transmission", 1997 Asilomar Conference, Nov., 1997, the contents of which are herein incorporated by reference.

[0007] An object of the invention is to alleviate this problem.

## SUMMARY OF THE INVENTION

[0008] The invention provides a signature waveform which introduces no or minimum signal distortion. The signature waveform is designed so that whenever the signal is above a maximum level, the signature waveform is subtracted from the signal peak position. As a result, the signal will not be saturated. The advantages such a signature waveform design are that the PAR can be reduced by as much as 6 dB, and no distortion is introduced into the transmission signal. The transmission signal has no distortion after peak deduction.

[0009] Accordingly the present invention provides a method of effecting peak reduction in a DMT signal, comprising the steps of creating a predetermined signature waveform, and subtracting said predetermined signature waveform from said DMT signal in the region of a signal peak whenever the DMT signal is above a predetermined maximum level.

[0010] In a preferred embodiment the signature waveform is generated by an iterative process from a predetermined starting waveform and passing it through time domain and frequency domain restriction units.

[0011] Typically the signature waveform is aligned with the time domain DMT output signal and multiplied by a scaling factor derived from the maximal value of the time domain DMT output signal. The result is passed through a bit shifter to match the number

bits per sample of the result with the number of bits in the samples of the time domain DMT signal.

[0012] The invention also provides an arrangement for effecting peak reduction in a DMT signal, comprising a first circuit for creating a predetermined signature waveform, and a second circuit for subtracting said predetermined signature waveform from said DMT signal in the region of a signal peak whenever the DMT signal is above a predetermined maximum level

## BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The invention will now be described in more detail, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 shows one embodiment of a circuit for reducing the PAR of a signal; and

Figure 2 is a block diagram illustrating the calculation of a signature waveform.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0014] As noted above, the object of the invention is to reduce the PAR (Peak-to-average ratio) of a signal to be transmitted. In accordance with the principles of the invention this is achieved by subtracting the signature waveform from the signal whenever the signal is above a predetermined maximum level. As a result, the signal will not be saturated.

[0015] The invention uses a few bits and a short vector for the signature waveform so that both the memory and computation requirements are minimized. Also, by carefully choosing the value *C*, as defined below, it is possible to achieve the maximum PAR reduction by 6 dB and maintain minimum signal distortion. The signature waveform s(k) is represented by a 256 byte vector (256 x 8 bits) with a maximal value of 0x 7f (0x indicates hexadecimal notation, so, for example, 7f would be 01111111 in binary notation).

[0016] Referring now to Figure 1, a practical implementation of the invention comprises an IFFT (Inverse FAST Fourier Transform) unit 100 which receives a frequency modulated DMT input signal X and outputs an IFFT time domain signal $x(k_1)$, which is represented as 16 bit numbers. The output signal $x(k_1)$ is fed to a subtractor 101.

**[0017]** In the meantime, the IFFT 100 unit calculates the maximal value of the amplitude (M) in a DMT frame. If the absolute maximal value (|M|) of the time domain signal ($x(k_1)$) is smaller than 0x08000, no action is required for PAR reduction, and the comparison output *C* is set to zero. Otherwise, if the maximal value (|M|) is equal to or greater than 0x08000, the threshold calculator 102 outputs the address location of the maximal value (I) in the series of samples and carries out the following steps:

**[0018]** If |M| is larger than 0x0FFFF, |M| is first saturated to a predetermined maximal value 0x0FFFF.

**[0019]** While the signature waveform is to be subtracted from the signal ($x(k_1)$), it must first be aligned with the signal peak bearing in mind that the signature waveform is only 256 bytes long. It must also be remembered that the signature waveform consists of only 8 bit samples whereas the signal consists of 16 bit samples.

**[0020]** Alignment of the signature waveform with the peak is achieved by taking IFFT output samples at addresses $k_1$ ranging from [I-128:I+127] (before the prefix, suffix and window are added), and subtracting the signature waveform multiplied by a suitable scaling factor *C* where *C* is determined as follows:.

$$|M| - ((C \times (0x0080)) \gg 7) = 0x08000$$

$$C = (|M| - 0x08000) \times \mathrm{sgn}(M)$$

**[0021]** The address $k_1$ for IFFT output x should be cyclically extended, i.e., if $k_1<0$, the true address should be $k_1+N$, where N is number of FFT points (For a normal DMT based DSL system, N=512, 1024, 2048, 4096 and 8192), and if k1>N-1, the true address should be k1-N.

**[0022]** The signature waveform s(k), which consists of 8 bits samples, is then multiplied by the scaling factor *C*, which consists of 16 bits samples, in multiplier 103. The result is a 23 bit number which is shifted 7 bits to the right in unit 104 to give a 16 bit number that is subtracted from $x(k_1)$ in subtractor 101.

**[0023]** The creation of the signature waveform is performed as shown in Figure 2. The signature waveform calculation is shown in Fig.2. First an initial frequency waveform is

selected and the frequency domain signal passed through and IFFT 201 to produce a time domain signature waveform s(n). This signal is then checked with a required threshold in unit 202 and any time domain samples which are above threshold are corrected to produce a modified time domain signal $s_1(n)$. This signal is passed through FFT unit 203 to produce a frequency domain waveform S(k).

**[0024]** This signal S(k) is then checked against a required frequency mask in unit 204 and any signals that are above the mask are corrected to comply with the mask requirements. The output of $S_1(k)$ of unit 204 is passed back into the IFFT 201 and the process repeated on an iterative basis unit either the waveform change becomes insignificant between successive iterations or a maximum number of iterations is reached.

**[0025]** An example of a time domain threshold for unit 202 is:

$$s_1(n) = \begin{cases} 1, & n=128; \\ s(n), & |s_1(n)| \le 0.5, n \neq 128 \\ 0.5 \times \mathrm{sgn}(s(n)), & |s_1(n)| > 0.5, n \neq 128 \end{cases}$$

**[0026]** In the above equation, it is assumed that the center point of the signature waveform is centered at n=128 and the threshold is a constant 0.5.

**[0027]** An example of frequency domain mask for unit 204 is:

$$S_1(k) = \begin{cases} S(k), & \text{k is in region 1 or small than required threshold} \\ \gamma_1 \times \mathrm{sgn}(S_1(k)), & \text{k is in region 2 and } |S_1(k)| > \gamma_1 \\ \gamma_2(k) \times \mathrm{sgn}(S_1(k)), & \text{k is in region 3 and } |S_1(k)| > \gamma_2 \end{cases}$$

**[0028]** Here, the region 1 belongs to transmitter frequency band which is not used. This band can be used for signature waveform with no constraints. The region 2 belongs to the

receiver frequency band and the corresponding threshold $\gamma_1$ is set such that it is equal to the required transmitter spectrum mask for the receive band, or in case there is no restriction on the transmit signal on the receiver band, $\gamma_1$ is set such that the generated echo signal to the receiver band is smaller than the requirement. The region 3 belongs to the transmitter band where data bits are modulated and $\gamma_2(k)$ is set as the 1/6 to 1/4 of the constellation distance which differs for different frequency subcarriers (k).

**[0029]** The above threshold selection will ensure that the signature waveform uses all possible frequency bands so that it can best approach an impulse function. At the same time, it will not violate any frequency requirements and will cause no signal distortion to both the far end and the near end receivers.

**[0030]** The invention provides an effective implementation for PAR reduction. The signature waveform design is such that it best approaches the impulse function and at the same time causes no or minimal distortion to both the transmitter and receiver signals.

**[0031]** The method described can be implemented with small amount of memory and fewer computations. By employing suitable parameters, the PAR reduction can be maximized.

**[0032]** The iterative method for the signature waveform creation ensures an optimal choice for the signature waveform. All possible frequency band are employed to create the optimum signature waveform.